EUROPEAN PATENT APPLICATION

(71) Applicant: FANUC LTD, 5-1, Asahigaoka 3-chome Hino-shi, Tokyo 191 (JP)

(72) Inventor: Inaba, Hajimu, 5-3-16 Asahigaoka, Hino-shi Tokyo (JP)
Inventor: Hiraizumi, Mitsuo, 581-16, Kitano-machi, Hachioji-shi Tokyo (JP)

(74) Representative: Billington, Lawrence Emlyn et al, HASELTINE LAKE & CO Hazlitt House 28 Southampton Buildings Chancery Lane, London WC2A 1AT (GB)

(54) Robot control method and apparatus.

(57) A system for controlling a robot, provided with a hand having a sensor, in accordance with stored robot command data and program data to carry a workpiece, from a plurality of workpieces stacked on a table, to a predetermined point by gripping the workpiece with the hand. When the hand is moved toward the stacked workpieces and the sensor senses an uppermost one of the workpieces, movement of the hand stops and the uppermost workpiece is gripped by the hand in accordance with a workpiece gripping program stored in memory. Upon gripping the workpiece, the hand is moved to the predetermined point in accordance with the next item of robot command data.

EP 0 092 433 A1
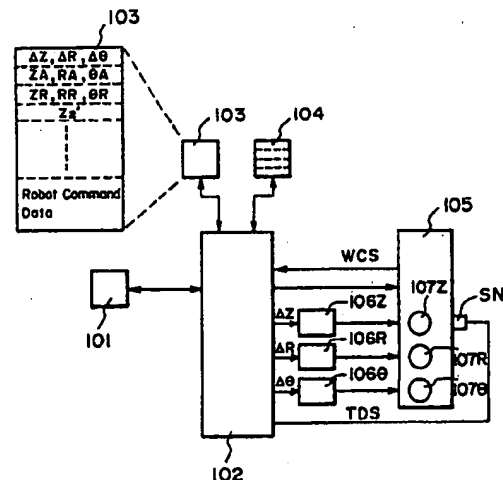
TITLE OF THE INVENTION

ROBOT CONTROL METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

This invention relates to a method and apparatus

5 for controlling a robot and, more particularly, to a

robot control method and apparatus which permit a robot

to be taught in a simple manner.

The rising cost of labor has given rise to a

demand for labor-saving measures and for improvement in

10 work procedures. Industrial robots have been put into

use to meet this demand and have been very successful

in doing so. Particularly outstanding results have

been achieved in plants having numerous machine tools

where industrial robots are used to perform such simple

15 services as changing the workpieces and tools

associated with each machine tool. The demand for such

robots has grown yearly.

With such playback type industrial robots, an

operator uses a teaching box to teach the service

20 operations in advance, and the taught data (referred to

as robot command data hereinafter) are stored in a

memory within a control unit. Whenever a request for a

service arrives from the machine tool side, a series of

the above robot command data is read out of the memory

25 sequentially, and the robot responds by servicing the

machine in repeated fashion as prescribed by the data.

The robot command data comprises point information

regarding a point at which a service is to be

performed, robot operating speed, and service codes
which indicate control of the hand at the point and
which instruct also the exchange of signals with the
machine tool side. In general, the teaching operation
5 mentioned proceeds by (1) setting a memory address at
which an item of robot command data is to be stored,
(2) positioning the robot at the service point by a
jog-feed (manual feed) operation, (3) setting position
information regarding the point, as well as the
10 magnitude of the speed command for movement up to the
point, and 4) setting the robot service codes which
specify the service to be performed at the point. A
series of robot operations for a machine tool is taught
by repeating the sequence (1) through (4).

15   Accordingly, as long as there are no problems with
the mechanism or control system of the robot, the robot
will be positioned at the predetermined operating speed
in accordance with the robot command data each time a
service is requested, after which the robot will
20 sequentially and correctly execute such services as
workpiece exchange, cleaning of machining scraps and
control of the hand.

        Robots of the above kind are often used in
operations of the kind shown Fig. 1, wherein a
25 multiplicity of unmachined workpieces W1 through W3,
stacked on a workpiece table WT, are to be gripped and
carried by the robot in sequential order. Since each
unmachined workpiece occupies a different position or

height relative to the table, the robot must be taught
each position individually. This obviously entails a
troublesome a teaching operation. Similarly, when the
robot is to stack machined workpieces on the table WT,

5 the position or height at which each workpiece is to be
released by the robot will differ. Again this involves
the complicated task of teaching the robot a position
for each and every workpiece in a stack.

SUMMARY OF THE INVENTION

10 An object of the present invention is to provide a
robot control system wherein the positions of
workpieces stacked on a table, or positions at which
workpieces are to be stacked on the table, can be
taught in a simple manner to enable gripping or

15 stacking of the workpieces.

Another object of the present invention is to
provide a robot control system wherein robot services
can be performed correctly, without teaching workpiece
gripping and stacking positions in an accurate manner,

20 by teaching data indicative of a position no higher
than a lowermost workpiece in a stack, and by providing
a sensor on a robot hand to sense workpieces in a
stack.

According to the present invention, the foregoing

25 objects are attained by providing a method and
apparatus for controlling a robot, provided with a hand
having a sensor, in accordance with stored robot
command data and program data to a carry a workpiece,

from a plurality of workpieces stacked on a table, to a predetermined point by gripping the workpiece with the hand. In accordance with point data stored in a first memory, and under the control of a processor, the robot

5   moves its hand toward a first point located above the stacked workpieces and then along the Z axis toward a second point in accordance with the point data to approach the plurality of stacked workpieces. The sensor senses an uppermost one of the stacked plurality

10 of workpieces and responds by delivering a detection signal to the processor which responds by causing the robot to suspend movement of the hand and by reading the program data out of a second memory. The processor then executes processing based on the program data to

15 cause the robot to close its hand on and grip the uppermost workpiece, the robot delivering a signal to the processor when the uppermost workpiece has been gripped. The processor responds by reading a subsequent item of point data out of the first memory

20 to cause the robot to move its hand to the predetermined point.

Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying

25 drawings, in which like reference characters designate the same or similar parts throughout the figures thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic perspective view showing a number of unmachined workpieces stacked on a workpiece table;

Figs. 2, 3 and 4 are views useful in describing
5 application of the present invention in a case where a number of unmachined workpieces are stacked on a workpiece table, in which Fig. 2 is a schematic perspective view, Fig. 3 a diagram showing the organization of robot command data and Fig. 4 a diagram
10 showing a path traversed by a robot arm expressed in cylindrical coordinates;

Fig. 5 is a block diagram illustrating a robot control apparatus embodying the present invention; and

Fig. 6 is a flow chart according to the present
15 invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference will now be had to Figs. 2 through 4 to describe an embodiment of the present invention for an application where unmachined workpieces W1, W2, W3,
20 stacked on a workpiece table WT as shown in Fig.2, are to be gripped and carried by a robot to a point P_3 one after another in the order mentioned. The robot, having a hand indicated at HD, operates in a cylindrical coordinate system (R, Z and θ axes) in
25 which points P1, P2, P2' and P3 have the coordinates (Z1, R1, θ1), (Z2, R1, θ1), (Z2', R1, θ1) and (Z3, R3, θ3), respectively. The robot hand HD is moved from a point, which is not shown, to the present point P1 at a

speed V1, from point P1 toward point P2' at a speed V2, and from a point Px, lying on the straight line connecting P1 and P2, to point P3 at a speed V3.

The hand HD has a sensor SN such as proximity sensing

5 means attached thereto for producing a signal when a workpiece is sensed. The position of the point P2' is lower than that of the point P2, namely $Z2 > Z2'$.

Robot command data has the organization shown in Fig. 3 and comprises items of point data PD1, PD2,

10 PD3... specifying respective points in space P1, P2', P3..., speeds for movement up to the particular point and so on. The first item worthy of noting with regard to the robot command data is that the Z coordinate (Z2') of the point data PD2 is taught as being no higher than

15 the position of any of the workpieces stacked along the Z axis. The preparation command G31 indicates that Z coordinate of the point data including G31 is taught as being no higher than the position of any of the workpieces stacked along Z axis. In other words,

20 according to a feature of the present invention, the Z coordinate of the point P2' which is below the lowermost unfinished workpiece W3 is taken as the Z coordinate of the point data PD2. As will become clear later, this means that Z coordinates of the workpieces need not be

25 taught in order to be gripped by the hand, thereby simplifying the teaching operation. The second item which should be noted is that the item of point data PD2 does not contain a robot service code for gripping

any of the workpieces Wl through W3.

To grip the first or uppermost unmachined
workpiece Wl and carry it to the predetermined point
P3, the hand HD is moved from the present point Pl
5 toward the stacked workpieces along the Z axis until,
at point Px, the sensor SN attached to the hand HD
senses the workpiece Wl, whereupon movement of the hand
is suspended. The path followed by the hand is as
indicated by the dashed line extending from point Pl to
10 Px in Fig. 4. Thereafter, the hand HD is caused to
close upon and grip the sensed workpiece Wl in
accordance with a grip command contained in a program
stored previously in the memory of a robot control
apparatus, described latter. When gripping of the
15 workpiece Wl is completed, a signal indicative of the
event is generated, in response to which the robot hand
HD is moved to point P3, which is specified by the item
of point data PD3. This is shown in Fig. 4 by the
dashed line extending from point Px to point P3.
20 Gripping and then carrying the remaining unmachined
workpieces W2, W3 to the point P3 is performed in
exactly the same manner, based on the same items of
point data PD1 through PD3. Thus, if the robot command
data is prepared as a series of point data including
25 data so taught as to indicate a position no higher than
the lowermost workpiece, then each of the workpieces Wl
through W3 can be gripped based solely on said series
of data. The position of each workpiece along the Z

axis need not be taught.

A robot control apparatus for practicing the above-described method of the invention is illustrated in Fig. 5 and the flow chart of processing is shown in

5 Fig. 6. The apparatus includes a teaching box 101 for teaching the series of robot command data illustrated in Fig. 3, a processor 102 which receives the taught data from the teaching box 101, a data memory 103 in which the taught data is stored by the processor 102,

10 and a registration memory 104 in which are stored program data for gripping unmachined workpieces stacked on the workpiece table, and program data for stacking completed workpieces on the workpiece table, the memory 104 being connected to the processor 102 so that the

15 processor may read said data. The processor 102 is also connected to a robot 105 having the abovementioned sensor SN attached to the hand thereof, the output TDS of the sensor being applied to the processor 102.

When the above-described system is set into

20 operation, the processor 102 reads the robot command . data out of the data memory 103 and controls the motion of the robot 105 in accordance with the items of point data PD1, PD2, PD3... constituting the robot command data.

25 Namely, at first path of the hand HD is controlled based on the point date PD1. When the point data PD1 is read, the processor 102 computes incremental values z_i, R_i, θ_i in each direction. Thereafter, the

processor 102 proceeds to store these values in the
data memory 103 as remaining amounts of movement ZR,
RR, θR respectively, and performs the following
operations to compute Z-, R- and θ-axis amounts of
5   movement ΔZ, ΔR, $\Delta \theta$ to be traversed during a
predetermined length of time ΔT:

$$\Delta Z = FZ \cdot \Delta T \quad \ldots \ldots \ldots (1)$$

$$\Delta R = FR \cdot \Delta T \quad \ldots \ldots \ldots (2)$$

$$\Delta \theta = F\theta \cdot \Delta T \quad \ldots \ldots \ldots (3)$$

10   The values of ΔZ, ΔR and $\Delta \theta$ are stored in a storage
area of the data memory 103 and are fed into the pulse
distributors 106Z, 106R, 106θ. Note that the period of
ΔT in the foregoing equations is a quantity preset as
a parameter. Further, FZ, FR, Fθ are the feed speeds
15   along the Z, R and θ axes, respectively.

Upon receiving the ΔZ, ΔR, $\Delta \theta$ inputs, each pulse
distributor, 106Z, 106R, 106θ executes a linear
interpolation simultaneously along the Z, R and θ axes
and generates distributed pulses PZ, PR, Pθ to rotate
20   the motors 107Z, 107R, 107θ. With each lapse of the
time ΔT, the processor 102 computes values of ΔZ, ΔR,
$\Delta \theta$ anew and accumulates the resulting values along the
respective axes. In other words, the processor 102
executes the operations given by:

25   $$ZA + \Delta Z \longrightarrow ZA \quad \ldots \ldots (4)$$

$$RA + \Delta R \longrightarrow RA \quad \ldots \ldots (5)$$

$$\theta A + \Delta \theta \longrightarrow \theta A \quad \ldots \ldots (6)$$

to update the coordinates ZA, RA, θA of the current

position occupied by the hand HD of the robot, which

coordinates are then stored in the data memory 103.

The processor 103 also performs the following

operations with each lapse of the time ΔT:

5
$$ZR - \Delta Z \longrightarrow ZR \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$RR - \Delta R \longrightarrow RR \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\theta R - \Delta\theta \longrightarrow \theta R \quad . \quad . \quad . \quad . \quad . \quad (9)$$

to update the remaining amounts of movement stored in

the data memory 103. When the processor 102 senses

10   that the conditions $ZR \geq \Delta Z$, $RR \geq \Delta R$, $OR \geq \Delta\theta$ hold,

namely that the remaining amounts of movement, ZR, RR,

θR along the Z, R and θ axes are equal to or greater

than the incremental values ΔZ, ΔR, $\Delta\theta$, respectively,

ΔZ, ΔR, $\Delta\theta$ are applied to the pulse distributor 106Z,

15   106R, 106θ. On the other hand, if it is sensed that

the conditions $ZR < \Delta Z$, $RR < \Delta R$, $\theta R < \Delta\theta$ hold, then ZR,

RR and θR are applied to the pulse distributor 106Z,

106R, 106θ. The hand is thus moved to the target

position P1. When the hand arrives at the target

20   position P1 (i.e. ZR=0, RR=0, θR=0), the processor 102

reads the next point data PD2 out of the RAM 103 and

then performs the proceeds to execute control

processing just as described above. When the point

data PD2 is read, the processor 102 causes the robot

25   105 to move its hand HD (Fig. 2) from point P1 toward

point P2'. Since the Z coordinate Z2' of point P2' has

been taught as being no higher than the the lowermost

unmachined workpiece W3, the proximity sensor SN

mounted on the hand senses the presence of the

uppermost workpiece W1 before the hand reaches the

point P2. The sensor SN produces a touch signal TDS

upon sensing the workpiece W1, the signal being applied

5 to the processor 102 which responds by immediately

suspending control of the robot based on the point data

PD2, and by reading the program data, stored in

registration memory 104, that calls for the robot hand

to grip the unmachined workpiece W1 from the stack of

10 workpieces on the table WT. Upon reading said program

data, the processor 102 executes the grip process step

and causes the robot 105 to grip the workpiece W1.

When the robot hand has closed firmly on the workpiece,

the robot 105 sends a grip complete signal WCS to the

15 processor 102, which responds by reading the point data

PD3 out of the data memory 103 to move the robot hand

HD from point Px to point P3.

On the other hand, if the coordinate z_a of the

current position becomes smaller than the Z coordinate

20 (z_2') of the point P2' without the generation of the

touch signal TDS, the processor 102 recognizes that all

workpieces W1~W3 have been machined and performs

gripping control of the workpieces stacked over the

distinct position P4 on the table WT (see dashed line

25 of Fig. 2).

The foregoing series of operations is repeated for

unmachined workpiece W2, which will be the next

workpiece sensed by the proximity sensor SN, and then

again for the final workpiece W3.

The foregoing description deals with the gripping and carrying of stacked unmachined workieces W1 through W3 from the workpiece table WT. It should be noted,

5   however, that the invention can also be applied to the stacking of completed workpieces, and to the loading and unloading of workpieces. By way of example, assume that the robot is to (1) grip an unmachined workpiece from the workpiece table, (2) load the workpiece onto a

10 machine tool where the workpiece is machined, (3) unload the completed workpiece from the machine, and (4) stack the completed workpiece on the workpiece table, the foregoing robot activities taking place in the described order. To achieve the foregoing

15 operations, the output TDS of the sensor SN could be applied to a counter for counting the number of times the signal TDS is generated, up to a total of four. Then, in accordance with the count, the processor 102 would read program data for gripping, loading, unload-

20 ing and stacking out of the registration memory 104 and then execute these operations based on the read data.

In accordance with the present invention as described and illustrated hereinabove, positional data is taught based on a position no higher than the

25 lowermost workpiece in a stack, and the sensor SR is provided on the robot hand HD to sense when to grip or release a workpiece. Teaching is thus simplified because the operator need not teach gripping and

stacking positions in accurate fashion.

As many apparently widely different embodiments of
the present invention can be made without departing
from the spirit and scope thereof, it is to be
5 understood that the invention is not limited to the
specific embodiments thereof except as defined in the
appended claims.

10

15

20

25

WHAT WE CLAIM IS:

1.   A method of controlling a robot, provided with a
hand having a sensor, in accordance with stored robot
command data and program data to a carry a workpiece,
5 from a plurality of workpieces stacked on a table, to a
predetermined point by gripping the workpiece with said
hand, comprising the steps of:

(a) moving the hand toward the plurality of
stacked workpieces in accordance with the robot command
10 data;

(b) suspending movement of the hand when the
sensor senses an uppermost one of the stacked plurality
of workpieces;

(c) gripping the uppermost workpiece with the
15 hand in accordance with the program data;

(d) generating a signal indicating that the hand
has gripped the uppermost workpiece; and

(e) moving the hand to the predetermined point in
accordance with a subsequent item of robot command
20 data, in response to generation of said signal.

2.   The method according to claim 1, further
comprising a step of repeating steps (a) through (e) to
grip and carry workpieces, remaining stacked on the
table, to the predetermined point.

25 3.   A robot control apparatus for successively
carrying workpieces, from a plurality of workpieces
stacked on a table along the Z axis, to a predetermined
point, comprising:

a robot having a hand for gripping and carrying
workpieces;

a processor connected to the robot for controlling
said robot in accordance with program data and robot

5   command data which includes items of point data, and
for receiving signals from the robot;

teaching means for teaching a series of the robot
command data and for applying the robot command data to
said processor;

10 a data memory connected to said processor for
having the robot command data stored therein for
subsequent reading by said processor;

a registration memory, connected to said
processor, for storing the program data inclusive of

15 data instructing said robot to close the hand in order
to grip a workpiece; and

sensing means provided on the hand of said robot
for delivering a detection signal to said processor
upon sensing the proximity of a workpiece;

20   said processor reading the robot command data out
of said data memory at the start of operation for
controlling the robot in accordance with each item of
point data in said robot command data, said robot
moving its hand toward a first point in accordance with

25 a first item of said point data and then along the Z
axis toward a second point in accordance with a second
item of said point data to approach the plurality of

stacked workpieces from above, said sensing means

sensing an uppermost one of the stacked plurality of

workpieces and responding by delivering the detection

signal to said processor which responds by causing the

5 robot to suspend movement of the hand and by reading

the program data out of said registration memory, said

processor executing processing based on said program

data to cause the robot to close its hand on and grip

said uppermost workpiece, said robot delivering a

10 signal to said processor when said uppermost workpiece

has been gripped, said processor responding by reading

a third item of point data out of said data memory to

cause the robot to move its hand to the predetermined

point.

15 4. The apparatus according to claim 3, wherein said

second item of said point data specifies a position

along the Z axis which is lower than the true position

of said uppermost workpiece.

5. The apparatus according to claim 4, wherein said

20 second item of point data specifies a position along

the Z axis no higher than the lowermost one of the

plurality of stacked workpieces.

25

Fig. 1

Fig. 2

Fig. 3

PD_1

V_1
R_1
Z_1
θ_1

PD_2

G_{31}
V_2
R_1
Z_2
θ_1

PD_3

V_3
R_3
Z_3
θ_3

Fig. 4

$P_1(Z_1, R_1, \theta_1)$

$P_3(Z_3, R_3, \theta_3)$

P_x

P_2
(Z_2, R_1, θ_1)

Fig. 5

Fig.6

```
                                    ┌─────────────┐
                                    │    Start    │
                                    └─────────────┘
                                           │
                                           ▼
                              ┌──────────────────────────┐
                              │ Step of reading the point │
                              │ data from the data memory │
                              └──────────────────────────┘
                                           │
                                           ▼
                                        ╱      ╲
                                      ╱  Step of  ╲
                                    ╱ discriminating ╲   No
                                  ◄────────────────────────
                                    ╲ whether or not G3l is ╱
                                      ╲ included in the ╱
                                        ╲ point  ╱
                                          ╲ data ╱
                                            │
                                           Yes
```

Step of performing normal robot control

Step of performing robot control in accordance with the point data

End ?   No

(A) ──► Yes

END   Yes

```
                    ╱      ╲
                  ╱  Step of  ╲
            NO  ╱ discriminating ╲
          ◄──────────────────────
                ╲ whether or not a touch ╱
                  ╲ signal TDS ╱
                    ╲ generates ╱
                        │
                       Yes
```

Step of stopping the movement of hand

(A) NO ◄── ZA < Z2'

Yes

Step of gripping the workpiece from the neighboring position

Step of gripping the workpiece in accordance with the gripping program read from the memory 104

```
                    ╱      ╲
                  ╱  Step of  ╲
            NO  ╱ discriminating ╲
          ◄──────────────────────
                ╲ whether or not a complete ╱
                  ╲ signal WCS generates ╱
                        │
                       Yes
```

0092433

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ³)
X,P L	EP-A-0 067 881 (FANUC) * Whole document *	1,2,4, 5	B 25 J 9/00 G 05 B 19/42
P,X L	EP-A-0 067 880 (FANUC) * Whole document *	1,2,4, 5	
P,X L	EP-A-0 068 026 (FANUC) * Whole document *	1,2,4, 5	
Y	US-A-3 306 471 (DEVOL) * Page 4 - page 6, line 70; figure 1 *	1,2	
Y	US-A-3 501 642 (BONNIERFORETAGEN) * Whole document *	3	

TECHNICAL FIELDS SEARCHED (Int. Cl. ³)

B 25 J   9/00
G 05 B   19/00
G 01 B   11/00

The present search report has been drawn up for all claims

Place of search THE HAGUE	Date of completion of the search 15-08-1983	Examiner RESSENAAR J.P.